Integrated Production Control Systems

MANAGEMENT, ANALYSIS, DESIGN
2E

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JAMES E. BAILEY

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Preface

"The manufacturing field presently is undergoing changes that would have been quite difficult to predict a decade ago." This was the first sentence of the first edition of this book and was written five years ago. That sentence is even more true today than when it was written.

All of manufacturing is moving toward a concept of integration in which manufacturing and design are no longer independent entities with designers hypothetically tossing over a design to be implemented into production without question of the design characteristics. Manufacturing capability and capacity have to be considered in the design phase.

Widespread productivity improvement through mechanization and automation—using microcomputers, programmable controllers, numerical-controlled machining, robotics, real-time computer control, computerized process planning, creative shop floor data capture systems, and other innovations—have created a need for a quantitative computer approach to production control. The heart of an automated manufacturing facility must be an integrated production control system; this allows for very quick planning and control changes. Quantitative approaches to production control are mandatory if computer-aided manufacturing systems are to perform up to their potential.

This second edition of *Integrated Production Control Systems* provides a computer-oriented, quantitative basis for analyzing production in modern manufacturing. A set of personal computer programs is available that parallels the text material. A major emphasis within the material is production information processing and flow, production planning, forecasting, material requirements planning and inventory control, and scheduling.

The reader will find that much of the material from the first edition has been completely rewritten. Computer-aided manufacturing and the relationship of production control to this extremely relevant body of technical knowledge are more heavily emphasized. In response to requests from users of the first edition, we have changed the symbols in the exponential smoothing forecasting material. The concept of disaggregation following an aggregate planning analysis is given far more attention. Presentation of material requirements planning (MRP) has been greatly simplified and, in the inventory control material, coverage of the lot-sizing material has been expanded. A section on the Japanese KANBAN system, as well as Just-in-Time, has been introduced, though the main emphasis for inventory analysis is still on the MRP approach. The end-of-chapter exercises have been expanded considerably.

By far the most exciting innovation is the development of the set of personal computer programs for the IBM personal computer. These programs have been written with user-friendliness in mind. You can obtain them by contacting the publisher. Programs cover growth forecasting (exponential smoothing and regression), seasonal/growth forecasting (BEDSEAS and WINTERS), aggregate planning and disaggregation analysis, material requirements planning, lot sizing and inventory control, job shop scheduling, critical path analysis, line-of-balance production monitoring and control, limited resource scheduling, and line balancing. The techniques used within the programs are described fully in the related text material. The advantage of these programs as a teaching vehicle is not merely to speed up the solution of homework problems, but to exercise the computer as a dynamic "what if" decision support tool. BASICA *listings* can be taken directly off the diskette containing the programs since nonprotected source coding is provided. The user can therefore modify the programs and experiment at will. Documentation and program examples are given in an appendix.

The text is oriented toward the junior or senior levels in quantitative business or industrial/manufacturing engineering programs. The material has also been found satisfactory as preparatory material for students entering master's programs from disciplines other than business or industrial engineering. Prerequisite mathematical knowledge is limited, for the most part, to introductory probability and statistics, in addition to college algebra. Classic optimization using linear programming and calculus is employed at a beginning level in a few sections, and, with minimal supplementary material, the reader can use this book without knowledge of operations research or calculus.

All ten chapters can be covered in a 45- to 50-lecture-hour course, assuming minimal prerequisites have been satisfied. Chapter 1 discusses the role of production control and the need for computer integration. Chapter 2 considers the important information flow inherent in the production control cycle and introduces computer-aided manufacturing concepts mandatory for the modern production control body of knowledge. Forecasting is treated in Chapter 3 and is of course, the key to much of the production planning activity. It is exemplified by the requirement for the application of aggregate planning and material requirements planning functions, which are covered in Chapters 4 and 5. Somewhat traditional inventory control, both purchasing and manufacturing, is presented in Chapter 6, although the lot sizing material is relevant to the previous MRP material while the traditional inventory analysis is pertinent to the traditional warehousing problem. Chapter 7 starts the scheduling material and covers the complex sequence scheduling material encountered in the job-shop production environment. Chapter 8 is oriented to project planning—critical path scheduling, PERT analysis, and line-of-balance monitoring. This material comes late in the text because of its scheduling connotation as well as its relationship to limited-resource scheduling, which is treated in Chapter 8. Finally, Chapters 9 and 10 cover limited-resource as well as personnel scheduling.

Documentation for running the 11 personal computer programs is given in Appendix B. (The programs require an IBM personal computer, or IBM compatible, with at least a DOS 2.0 operating system with BASICA.) As indicated earlier, it is anticipated that many readers might want to modify programs to suit their own needs. Because source code is released to the public, the programs cannot be warranted to be error free even though extensive testing has been done with the production control course in industrial engineering at Arizona State University. The authors will welcome constructive comments regarding these programs as well as corrections of errors by users. We will attempt periodically to get such corrections out, to users who submit their names and addresses to us for a user list.

It is not possible to acknowledge everyone who has contributed to this book. Many classes of IEE 461 and IEE 502 at Arizona State University have tested the course material and the ancillary programs. It is well-known that current students are not bashful in expressing their views, which we have found to be very beneficial and constructive. Special appreciation has to be tendered to Eric Du and Ming Liu, graduate students in our Industrial Engineering Department, who showed great creativity and skill in working with us on the computer diskette. It is working with such students that makes teaching a highly rewarding profession, and to get paid as well is truly a treat. As in the first edition, we continue to express our appreciation to Vinod Sahney, Jay Miller, John Estes, John Field, and Glenn Dunlap for their constructive comments and aid. Similarly, thanks have to go to the Garrett Turbine Engine Company for allowing us to use illustrations and pictures; Garrett's Terry Taylor and John Vernon were especially helpful. Inclusion of material relating to the "paperless" factory would not have been possible without help from Factorial Systems, Incorporated, and Tandem Computer Systems, Incorporated. Dr. William Balcezak, Factorial President, graciously allowed use of Factorial material. The faculty of our Industrial Engineering Department have to be thanked for providing a group atmosphere that is conducive to developing a text of this nature. What a great thrill it is to be associated with an academic giant such as Arizona State University. As in the first edition, special thanks goes to Elinor Lindenberger, our manuscript typist. We repeat what we said in that first preface: Elinor demonstrates a personal strength and character that lifted the authors through some of the discouraging moments that can occur in an activity such as text writing. To Elinor, we would like to say

Grace was in all her steps, heaven in her eye,
In every gesture dignity and love
FROM *PARADISE LOST* BY MILTON

David D. Bedworth
James E. Bailey

Tempe, Arizona
January 1986

Contents

APPENDICES

CHAPTER 1

The Role of Production Control

The first step, my son, which one makes in the world, is the one on which depends the rest of our days.

VOLTAIRE

Formalized production control, in its earliest applications, was directed primarily at the production of manufactured goods. The purpose for production control was, and still is, to effectively utilize limited resources in the production of goods so as to satisfy customer demands and create a profit for investors. Resources include the production facilities, labor, and materials. Constraints, on the other hand, include the availability of resources, delivery times for the products, and the policies of management.

Effectively using constrained resources is the task of the production control activity in a manufacturing organization. It has become clear, primarily since World War II, that production control functions of planning, forecasting, scheduling, and inventory control can also be applied to organizations other than manufacturing. Thus, an approach used satisfactorily in scheduling appliances through an assembly line might be equally valid in sequencing patients through a hospital X-ray facility. Inventory control procedures developed for manufacturing might be equally beneficial to a bank or department store. Prediction of sales to allow better planning of a manufacturing facility over future time periods might be used in determining the number of hospital beds to authorize in the expansion of health services. In this book, the illustrations deal with the manufacturing process, but the reader should be aware that there is a much broader spectrum for production control application.

The Gantt or bar chart, as it is commonly known, was developed in World War I by Henri L. Gantt as a simple approach to scheduling. The Gantt chart, as will be seen in Chapter 8, provides a simple means to study and communicate complex relationships; it graphically illustrates when related tasks can be started so that precedent constraints are maintained and limited resources are well utilized. The ability to simplify a complex problem is the ultimate virtue of good management science. Those who would complicate the process of solving real-world problems are destined for frustration. Those who follow Gantt and present intuitively obvious solutions will see their efforts employed and their careers rewarded. It is hoped that the reader will concentrate on developing an intuitive understanding while learning to present obvious solutions.

In any organization, the utility of production control is to increase productivity. A proper definition of productivity is the ratio of the value of goods and services produced divided by the value of resources used in production. Resources are being wasted if machines or people are idle because there is no work or if parts remain in inventory because a machine is not available. The role of production control is to reduce this waste by intelligently coordinating the availability of people, equipment, and materials. Innumerable organizations have lost vast sums of money and even failed, because they had too much inventory or too much capacity. Productivity improvements can be made through improved designs or more efficient production methods. Intelligent production control can also improve the productivity of any manufacturing or service facility.

1.1 PRODUCTION CONTROL AS AN ORGANIZATIONAL ACTIVITY

In the final analysis, the task of production control activity is to interpret the conflicting objectives of production, sales, and finance, then to reconcile them into coherent production plans and inventory policies. The role of the shop-floor people is to meet the schedule. Obviously, they would like a schedule that is sufficiently loose so that it can be met even when equipment breaks down, people stay home, and scrap parts are discovered. The role of sales is to maximize shipments and minimize delivery delays. Obviously, sales people would like large inventories, especially of finished goods. The role of finance is to minimize the amount of capital tied up in facilities, people, and inventory. Obviously, those in finance would like a lean shop and low inventory levels. The role of the total organization is to balance these conflicting needs of the organization's components.

The question then becomes, Where should the production control activity fit within the organization? Should it report to the production executive, the sales executive, or the comptroller? There are probably as many answers to this question as there are manufacturing or service organizations. This is as it should be. Since production control performs many functions, it ought to be housed organizationally where these functions can best be performed. Perhaps a company should have centralized production control, so that the conflicting needs can be consistently balanced. This centralized department would be responsible for creating demand forecasts and for seasonal planning of production levels. It might also monitor and control sales, shipping levels, and raw material purchases, and be responsible for setting employment and overtime levels. Issuing specific production and purchase orders might be left to individual units, which are better able to make the short-term adjustments as conditions change. Further, the detailed shop schedules indicating what to run next and using what equipment are delegated to the lowest level of management, which are most closely tied to the hourly situation. The best advice relative to organizational location is to put the various production control activities reasonably close to the source of information needed to make good decisions while spreading them out so that no single function (i.e., production, sales, or finance) seriously biases the decisions.

In analyzing a production control activity, certain questions should be asked. The best production control structure is the one that can satisfactorily answer these questions:

1. Are all the activities of planning, scheduling, and inventory management identified and housed somewhere?
2. Do the people responsible for making the necessary decisions clearly understand their roles, the objectives of their decisions, the information available to them, and the accepted procedure for making decisions?
3. Do the people responsible for making the decisions have an accurate and timely information system?
4. Is there a system to identify when nonroutine situations occur and fast, unusual decisions are needed?
5. Are all the interfacing organizational activities content with the production control function, and are they unlikely to confuse or sabotage its decisions?

If all of these questions can be resolved satisfactorily, the production control function is well organized. The concern then becomes whether the people involved have the best available decision-making techniques. The development of these techniques is the topic of this text.

1.2 PRODUCTION CONTROL AS A SYSTEM

The concept of computer-integrated production control is presented in Chapter 2, primarily to show the integrated flow of data and information between the shop floor, various production control systems, and manufacturing management. Just as production control interrelates with functions outside itself, so do the components within production control have a complex flow of interactions. A simplistic view of these interactions might be as diagrammed in Figure 1.1. It should be apparent that decisions in one component—say, scheduling—have a distinct effect on other components. For example, one way to ensure that production is never slowed by lack of materials is to inventory an excess of those materials.

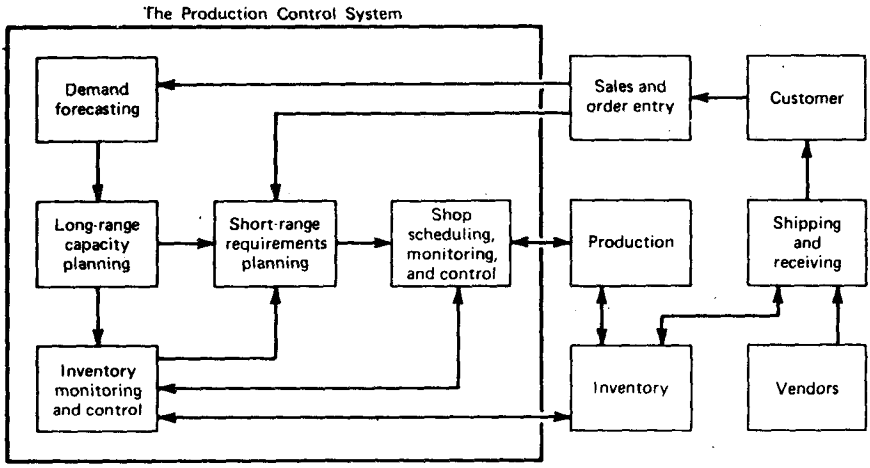

FIGURE 1.1 Representative production control information system.

This might simplify the scheduling activity, but it does so at the expense of higher inventory expenses. For another example, one can ensure that production never misses a due date by increasing the delivery times, thus pushing customer demands off into the future. This makes the scheduling problem easier, but at the expense of customer satisfaction. The production control activity is a system, and it must be viewed in its totality. It may not always be wise to require that production resources never be idle or that inventory costs be minimized or that all due dates be met. The objective of the production control system should be the objective of the total organization. Decisions that complement sales, production, and inventory are preferable to those that optimize only one function.

To illustrate the production control system, the reader should study Figure 1.1. The system is shown as a cyclic activity starting with the customer and moving counterclockwise through the figure. At this point we are concerned only with the activities located inside the larger box labeled "The Production Control System." A series of events represented in this box is introduced here and covered in detail in subsequent chapters of the text.

Demand forecasting is the starting point for production control activity. For each class of product or service the future must be predicted. It is not unusual to have a lead time of many months between the time an order is placed to purchase raw materials and the time those materials are transformed and shipped out as finished goods, in which case the forecast must be for months into the future. This is called the forecasting horizon. In some cases, it is easy to predict sales for one to two years into the future. The delivery time between firm-order entries and deliveries may be a large fraction of the needed forecasting horizon. In other cases accuracy beyond actual order entries may be very difficult to attain. Without accurate forecasts it is impossible to accomplish the long-range capacity planning activity.

Capacity planning is the second step in the production control chain of events. The need is to know how many people to employ, how much overtime to schedule, and how much inventory to hold so that actual demand is economically met. If insufficient capacity or inventory is available, demand cannot be met and customers may be lost. If too much capacity and inventory exist, the company will be in a serious cash-flow bind. If the wrong products are in the pipeline, the company will be hurt at both ends, with unsatisfied customers and unsalable products. Without a reasonably accurate forecast of future demand, long-range capacity planning is not possible.

One concern of capacity planning is the amount of inventory to be held. An often-used plan in the face of cyclic demand is to build more than is needed during slow periods, thereby increasing inventory. Then, when demand is high, it can be met, in part from inventoried items. Therefore, inventory levels will vary from period to period. With these variations in inventory, the quantities made on each production order will also vary. The control of inventory is the act of comparing what is actually on hand with the desired quantity. Inventory control thus is affected by the decision made in capacity planning.

A second activity that feeds off of the capacity planning output is short-range requirements planning. This activity also responds to the decisions of inventory control. In the near term, the need for production from rough machining to final assembly must be determined. In effect, the activity is one of looking at near-term production capacity and goals, existing inventory levels, and discrepancies between those levels and desired inventory, then creating a master schedule of what to do in each production department during the next week or month. To some extent, inaccuracies in the forecasted demand and changes in the capacity plan can be overcome at this stage. Items that need faster or greater production can be "red-tagged" as urgent. Those items whose production levels can be reduced are easily handled with relatively minor impact on inventories. The amount of overtime and/or undercapacity can be adjusted. Thus, there is a degree of flexibility within the broader limits of the capacity plan. The resulting output is the short-range requirements plan, or master schedule.

The master schedule is made without reference to the dynamic changes in the shop situation. If people fail to arrive for work or if a machine breaks down, the schedule must be changed. If scrap parts are found or tooling is temporarily unavailable, the schedule must be adjusted. The master schedule, then, identifies the weekly production goals for each department but does not determine how those goals are to be met. This is the role of the shop scheduling activity. At the beginning of each shift, the shop foreman must review where he is in relation to the master schedule and what resources are available to him. He must then decide what to do during the shift, in what sequence the shop orders should be accomplished, and what resources to devote to those tasks. These production control decisions are then passed on to the production employee.

Thus, the production control activity is a chain of interrelated events that functions as a system. The decisions are made for different horizons in time and with different degrees of accuracy. Yet they must all occur if the ultimate objective is to be met: that is, to use limited resources effectively to produce goods that satisfy customer demands and create a profit for investors.

1.3 SYSTEMS PLANNING AND ANALYSIS

Any complex system with interacting components, such as that described in Figure 1.1, requires a systematic approach for planning and analysis if the objective is to benefit the *overall* organization in some manner, and not just to benefit a select few of the interacting components.

One approach to the design of a production control system is to use the traditional systems approach (also referred to as the operations research approach). Steps involved in this approach include the following:

1. Determining the objectives of the system.
2. Structuring the system (defining) and setting definable system boundaries.
3. Determining the significant components that make up the system.
4. Performing a detailed study on the components *in light of* the overall system.
5. Synthesizing the analyzed components into the system.
6. Testing the system according to some performance criterion.
7. Improving the performance by cycling through steps 2 through 6 as needed.

This approach to problems with interacting components is used in many places in this text. As would be true with experienced problem solvers, the steps are not pointed out in the solution approaches, but the reader should readily see the approach in such areas as the following:

1. Determining which forecasting model yields sufficiently accurate demand forecasts at the least cost (Chapter 3).
2. Balancing the costs of inventory, overtime, jobbing out, and stock-outs while satisfying fluctuating demand forecasts (Chapter 4).
3. Evaluating inventory policies that minimize overall costs of ordering and holding inventories (Chapters 5 and 6).
4. Determining an assignment of tasks to production stations and the sequence of tasks on each station to maximize use of facilities and minimize late deliveries (Chapter 7).
5. Balancing overall project costs and durations in network-oriented projects (Chapter 8).

6. Determining which assignment of tasks to production stations balances work load and maximizes flow in network-oriented projects (Chapter 9).
7. Determining appropriate work days and shifts for people to reduce idle time while satisfying demand for labor (Chapter 10).

One philosophical comment should be made concerning step 7 of the systems approach—the act of improving a systems performance may be far more expensive than the return obtained from the improvement. As an example, consider the case of a company that engages a prominent consulting firm to improve the company's forecast procedures. If $250,000 is required to perform that study but the potential return from improved forecasts is $10,000 a year, should the improvement analysis be made? In many cases the answer is no. A thorough analysis of the potential benefits to accrue from an improvement effort should be made before embarking on the improvement project. To illustrate the systems approach, a simple case example using the concepts presented in Figure 1.1, along with some hypothetical data and assumptions, is presented in Section 1.4.

1.4 CASE STUDY

This case study introduces the reader to the production environment. The people involved and their conflicting interests will be presented while potential problems inherent with implementing production control systems are discussed. A key point to be made from the case study is that workers from the shop floor should be involved in production control system design. Satisfying the production control needs, as suggested by the production worker, is more important than the mathematical *elegance* of an "optimization" technique design.

In one month, Jack Kelly, senior staff IE at McCully Manufacturing, will have to report on a pilot effort to implement a computer-integrated shop floor management system. Jack and Lana Field, a systems analyst, have been developing this system for the Heat Treat Department for about a year. If the pilot study can be shown to work, a major investment will be made in plantwide computer-integrated manufacturing (CIM).

Last year, the company grossed about $50 million with its line of commercial and home-use power tools. Their major products are saws, drills, sanders, routers, shapers, and other wood-working tools. The President, Mr. Pearson, believes the next growth step for McCully will be to capture large contracts from nationwide retailers to supply tools under the customer's brand name. Marketing has acquired several commitments to order but at a lower price than is presently possible.

Thus, to capture this new business, the cost of manufacturing will have to be cut in half. Estimating future volume at $125 million, Pearson has ordered new manufacturing technologies to yield half the needed cost reduction and better production control to yield the other half. Jack Kelly convinced the president